BR and CP Asymmetries in B→hh' at CDF

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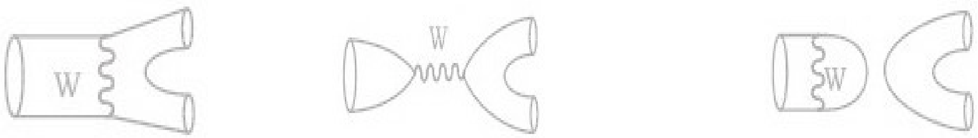
for the **CDF collaboration**



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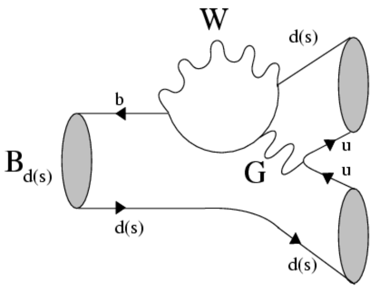
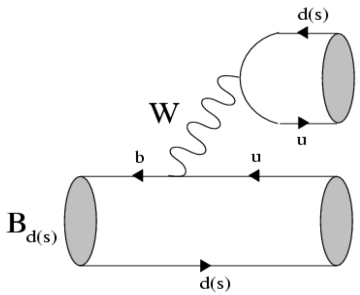


MOTIVATION



- Charmless 2-body B decays important tools for understanding the CKM matrix and looking for new physics.
  - BR and A_{CP} can be predicted and are sensitive to CKM parameters (γ)
  - variety of amplitudes involved requires measuring many channels in order to eliminate hadronic unknowns.
- Hadronic machines offer large yields and additional access to Bs and barions. Combining Bs and Bd observables provides helpful ways to eliminate unknowns and constraining CKM parameters.
- Special interest: $B_s \rightarrow K^+K^-$. CP-eigenstate with sizeable BR, allows measuring $\Delta\Gamma_s$.
- This talk: CDF results on B hadron decays into $h^+h'^-$ where h=K or π (PP)
  [See talk by M. Rescigno for other charmless modes at CDF]

Example: $B_s \rightarrow KK$ vs $B_d \rightarrow \pi\pi$

Time dependent CP asymmetries

$$A_{cp}(t) = A_{cp}^{dir} \times \cos \Delta m t + A_{cp}^{mix} \times \sin \Delta m t$$

$$A_{cp}^{dir}(\pi^+\pi^-) = -\frac{2d \sin\theta \sin\gamma}{1-2d\cos\theta\cos\gamma+d^2}$$

$$A_{cp}^{dir}(K^+K^-) = \frac{2d\frac{1-\lambda^2}{\lambda^2}\sin\theta\sin\gamma}{1+2d\frac{1-\lambda^2}{\lambda^2}\cos\theta\cos\gamma+(\frac{1-\lambda^2}{\lambda^2})^2 d^2}$$

$$A_{cp}^{mix}(K^+K^-) = \frac{\sin 2\gamma+2d\frac{1-\lambda^2}{\lambda^2}\cos\theta\sin\gamma}{1+2d\frac{1-\lambda^2}{\lambda^2}\cos\theta\cos\gamma+d^2(\frac{1-\lambda^2}{\lambda^2})^2}$$

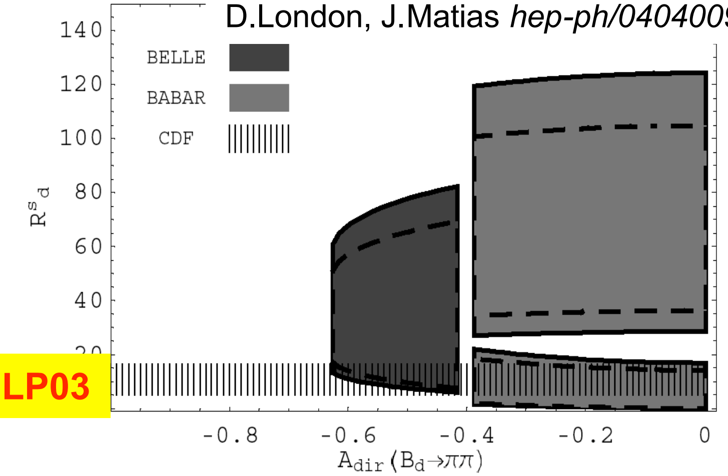
$$A_{cp}^{mix}(\pi^+\pi^-) = \frac{\sin 2(\beta+\gamma)-2d\cos\theta\sin(2\beta+\gamma)+d^2\sin 2\beta}{1-2d\cos\theta\cos\gamma+d^2}$$

$$A_{cp}^{mix}(J/\psi K_s) = \sin 2\beta$$

R.Fleisher hep-ph/0405091

Many observables related by U-spin relationship, determine angle γ and provide tests for NP

D.London, J.Matias *hep-ph/0404009*



$$H = \left(\frac{1-\lambda^2}{\lambda^2}\right)\left(\frac{f_K}{f_\pi}\right)^2\left[\frac{BR(B_d \to \pi^+\pi^-)}{BR(B_d \to K^\pm\pi^\mp)}\right] = \frac{1-2d\cos\vartheta\cos\gamma+d^2}{\left(\frac{\lambda^2}{1-\lambda^2}\right)^2+2\left(\frac{\lambda^2}{1-\lambda^2}\right)d\cos\vartheta\cos\gamma+d^2}$$

$$R_d^s = \left[\frac{BR(B_s \to K^+K^-)}{BR(B_d \to \pi^+\pi^-)}\right] = \left(\frac{1-\lambda^2}{\lambda^2}\right)\left|\frac{C'}{C}\right|^2 \frac{\left(\frac{\lambda^2}{1-\lambda^2}\right)^2+2\left(\frac{\lambda^2}{1-\lambda^2}\right)d\cos\vartheta\cos\gamma+d^2}{1-2d\cos\vartheta\cos\gamma+d^2} F_{ps}$$

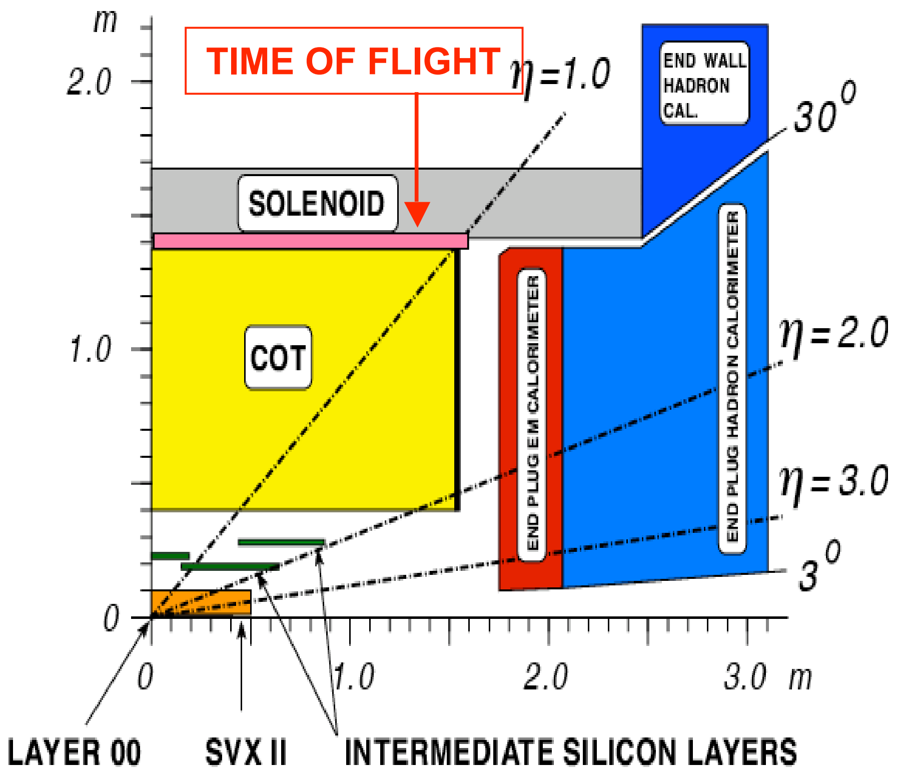
Branching Ratios

Phase space factor = 0.92

QCD sum rules: 1.76+0.15-0.17 (A.Khodyamirian et al., Phys.Rev D68 114007)

CDFII the first hadronic experiment to study B → hh

- Tracking:
  - Central Drift chamber 96 layers (COT) $\sigma(P_T)/P_T^{\,2} \sim 0.1\%\ \mathrm{GeV}^{-1}$
  - Silicon Vertex detector (1+5+2 layers) I.P. resolution 35μm@2GeV
- Trigger:
  - eXtremely Fast Tracker (at L1) and Silicon Vertex Trigger (at L2). Allow very powerful triggers on hadronic B decays, based on track impact parameters to primary vertex
  - Designed with this application in mind



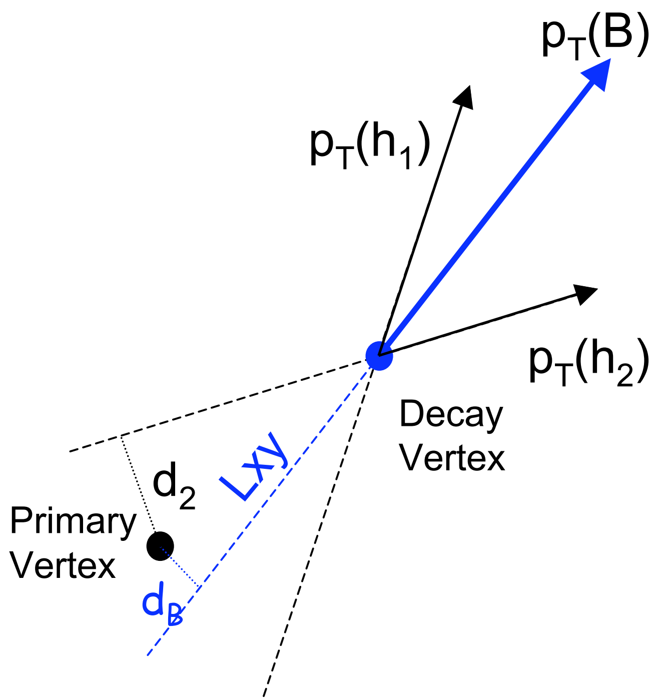
- First results with 65 pb^{-1} shown at LP03.
- Today: update with 180pb^{-1} (4x statistics)

Sample Selection

- Trigger on track pairs with large impact parameters
- Track cuts: Pt, d, (PT1+PT2)
- B candidate cuts: Lxy, $|d_B|$
  (require candidate pointing back to primary vertex)
- Isolation cut: rejects light quark background
  (analog of event shape for e+e-)

$$I(B) = \frac{Pt(B)}{Pt(B) + \sum_{cone} Pt_i}$$

Important handle: 85% efficient on signal, reduces background by factor 4



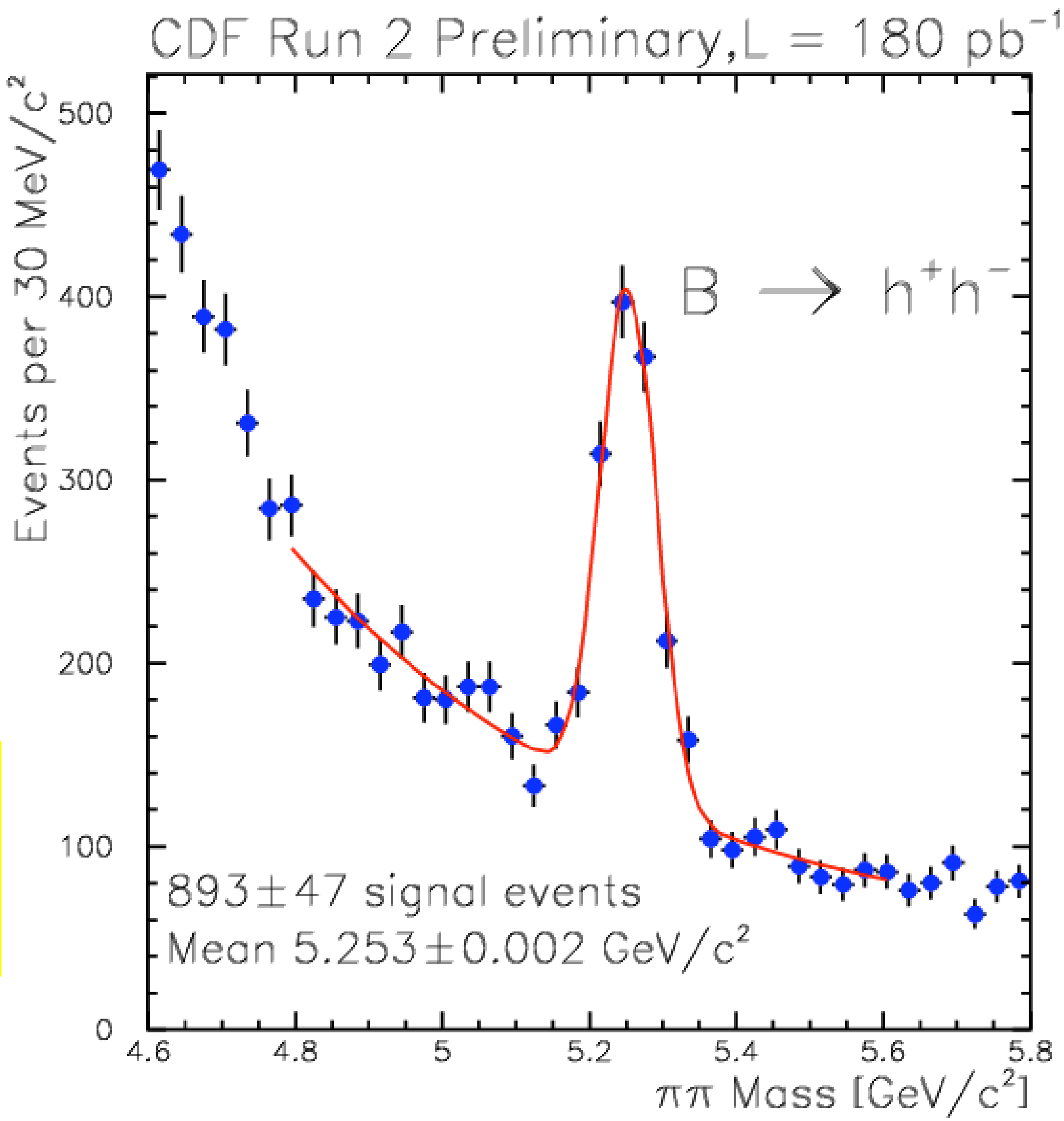
- All cuts simultaneously optimized for maximum S/sqrt(S+B)
  (S from MC, B from data sidebands)
- Optimize resolution on BR/A_{CP} measurements
  (valid for “large” components; not necessarily best for rare modes)

Signal

- $Pt_1, Pt_2 \geq 2$ GeV
- $Pt_1 + Pt_2 \geq 5.5$ GeV
- $|d_1|, |d_2| \geq 150\ \mu m$
- $L_{xy} \geq 300\ \mu m$
- $|d_B| \leq 80\ \mu m$, $d_1 \cdot d_2 < 0$
- Iso > 0.5

Signal: 893±47   S/B>2

N.B. S/B ~10^{-8} at production



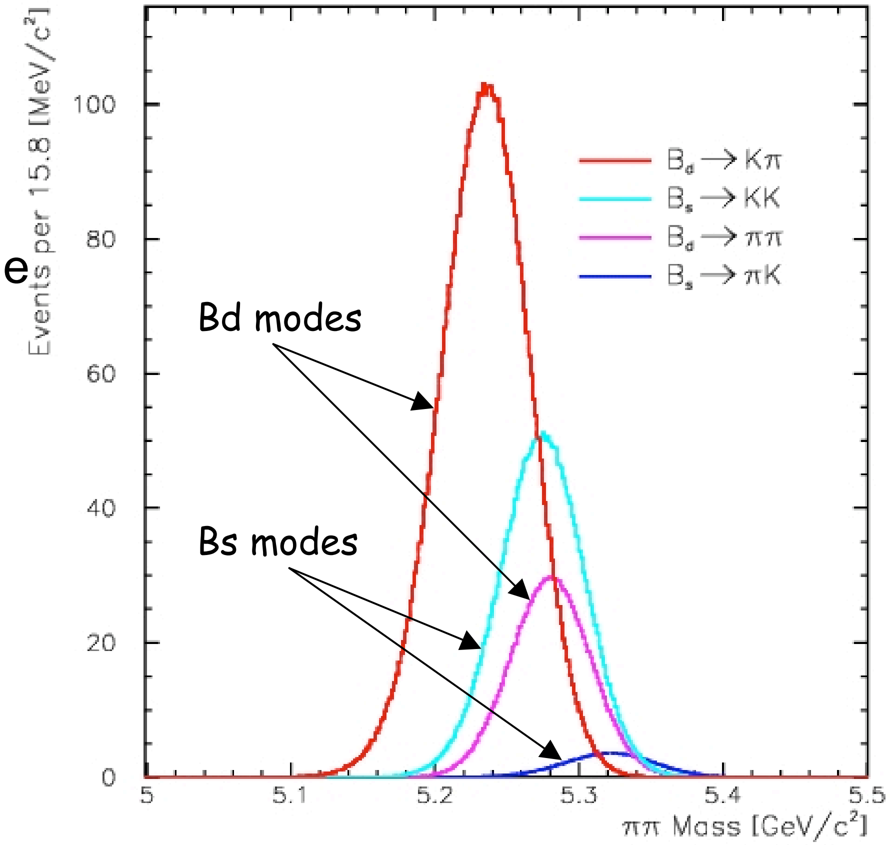
Separation of individual modes

- The 4 major expected modes overlap to form a single unresolved bump
- Approach: use Mass+kinematics+track PID in an unbinned Max-Likelihood fit $\Rightarrow$ extract the fraction of each component.

•Likelihood combines:

–Exp+const background with floating pion/Kaon ratio

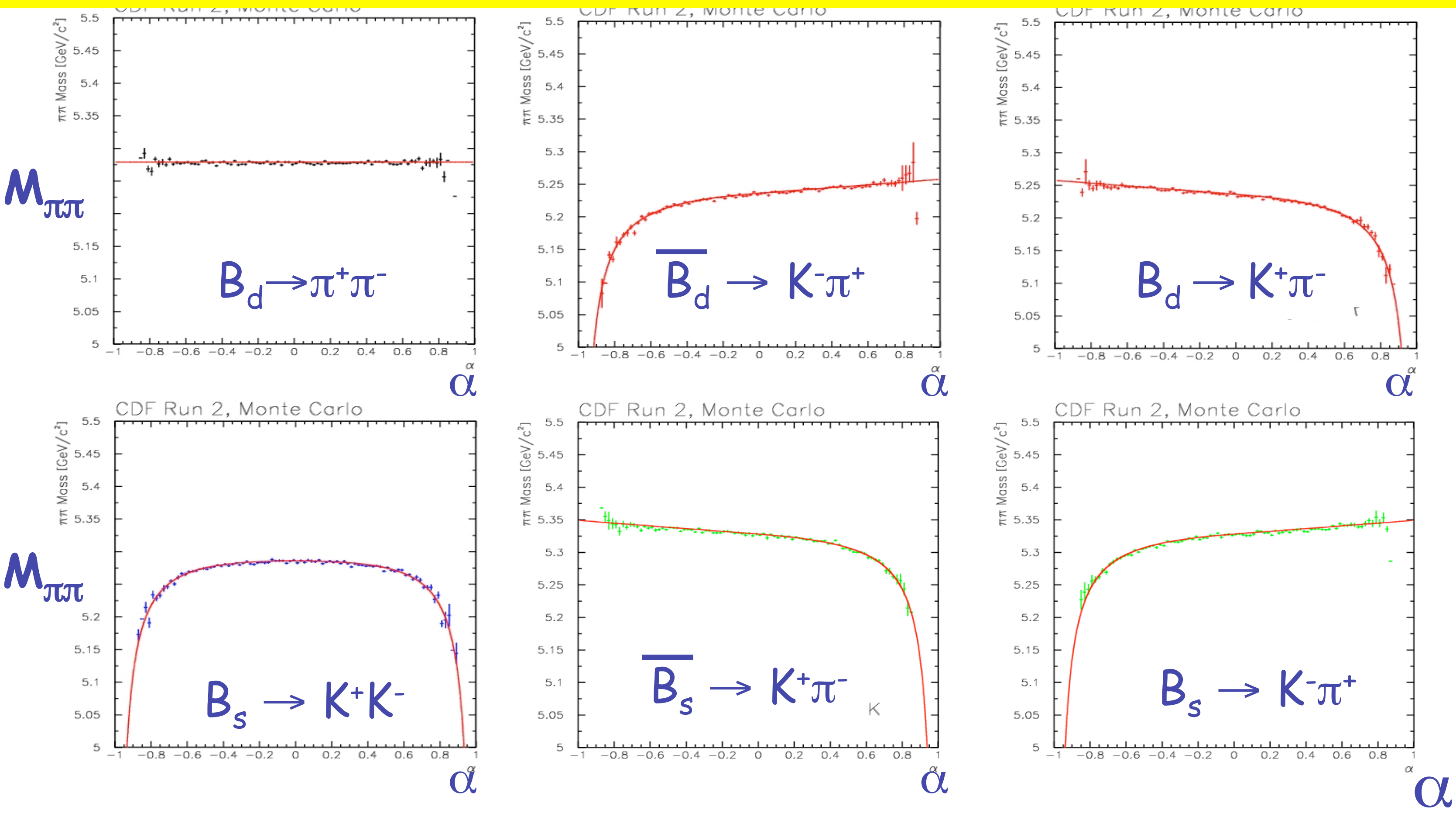
–Sum of signal channels, each having the form Mass*kinematics*PID



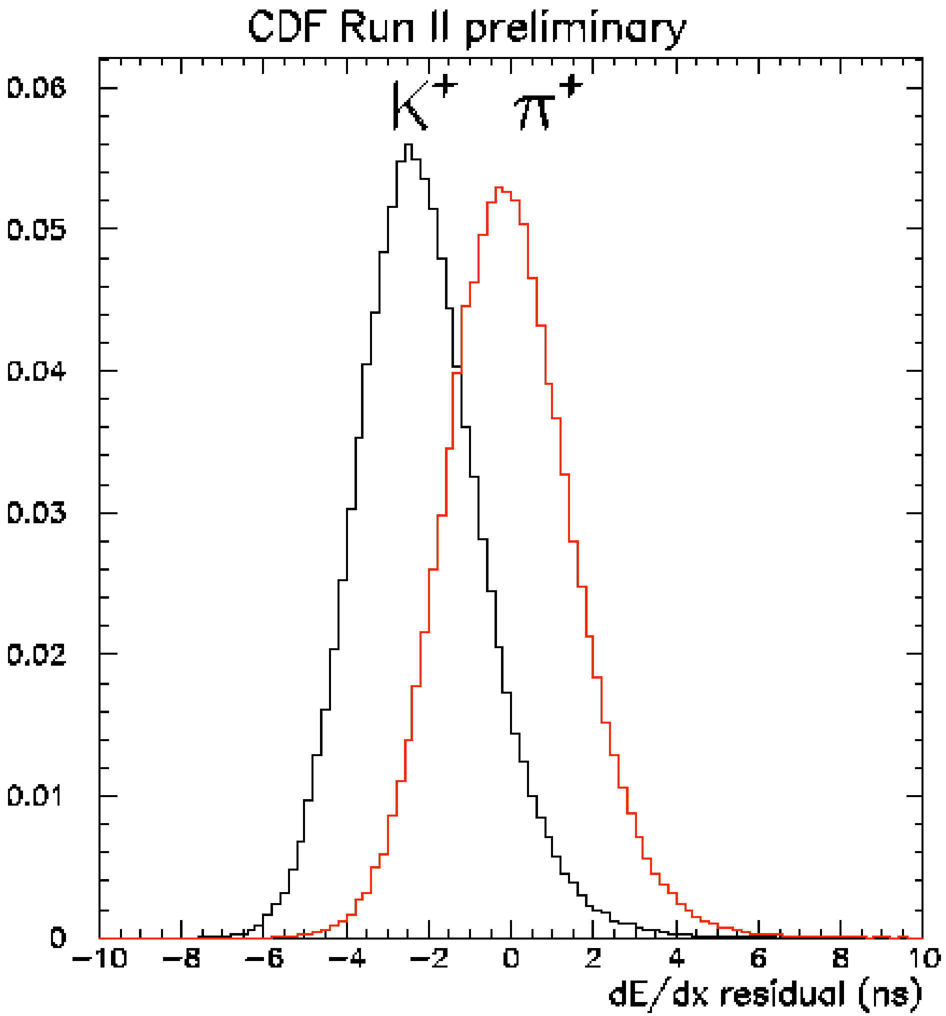
Achieve resolution ~30% worse than B-factories for same number of signal events

Separation from Kinematics

Mass ($\pi\pi$ hypothesis) vs signed momentum imbalance α=[1-p1/p2] x q1.
discriminates amongst signals and between flavors for self-tagging decays.
All 4 possible mass assignments (strongly correlated) depend on them
$\Rightarrow$ *(α, $M\pi\pi$)* carry all relevant information



Separation from PID (dE/dx)



- K/π separation: **1.4σ** @P_T>2 GeV/c
- Improved since LP03 due to new time-dependent calibrations on CDF's huge $D^{*+} \rightarrow D^0\pi^+$ sample.
- This PID performance implies statistical separation of K-pi with resolution 60% of a "perfect" PID.
- Control of systematics:
  Residual gain/baseline fluctuations cause correlated fluctuations of tracks in same event. They have been measured and explicitly included in the fit.

Fit Results

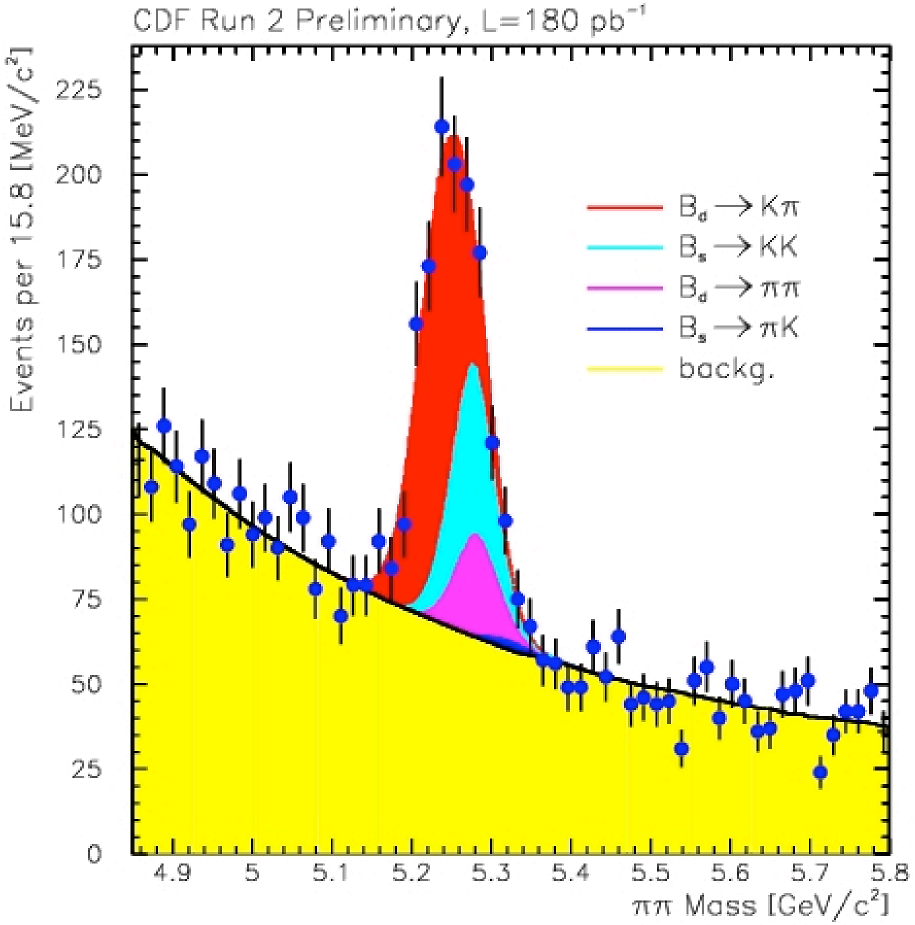
parameter	value
$f(B_d \to \pi\pi)$	0.15 ± 0.03
$f(B_d \to K^{\pm}\pi^{\mp})$	0.57 ± 0.03
$A_{CP}(B_d \to K^{\pm}\pi^{\mp})$	-0.05 ± 0.08
$f(B_s \to K^{\pm}\pi^{\mp})$	0.02 ± 0.03
$f(B_s \to KK)$	0.26 ± 0.03

Decay	# B
$B_d \to K^+\pi^-$	509
$B_d \to \pi^+\pi^-$	134
$B_s \to K^+ K^-$	232
$B_s \to K^-\pi^+$	---

Largest sample of fully reconstructed Bs decays.

$B_d \to K^+\pi^-$ 509/180 pb^{-1}

(comparable to old Babar 589/81 fb^{-1})



Raw results need corrections for efficiency differences ~10% between channels

Systematics

- Dominant systematics:
  - dEdx calibration
  - Isolation cut efficiency (measured from CDF samples of Bs→J/psi phi , Bs → $D_s\pi$, Bd→J/psi K^{0*})

GeV/c	$\epsilon_{Iso}(B_d)$	$\epsilon_{Iso}(B_s)$	$\epsilon_{Iso}(B_u)$	$\epsilon_{Iso}(B_d)/\epsilon_{Iso}(B_s)$
$p_T(B) < 6$	57.5±9.7	70.1±14.6	67.7±7.2	0.82±0.22
$6 < p_T(B) < 10$	84.6±2.4	84.8±5.7	85.1±1.2	1.00±0.08
$p_T(B) > 10$	93.8±1.2	90.4±2.8	93.6±0.8	1.04±0.03

- Both systematics are of *statistical* origin, and expected to go down with sample size (they did from 65 to 180 pb^{-1})

Results for the Bd sector

	CDF/180 pb^{-1}	Babar/200 fb^{-1}	Belle/140 fb^{-1}
$N(B_d \rightarrow K^+\pi^-)$	509	1600	1030
$\frac{BR(B_d \rightarrow \pi^+\pi^-)}{BR(B_d \rightarrow K^+\pi^-)}$	0.24±0.06±0.04	0.26±0.036±0.015*	0.24±0.035±0.018*
$A_{CP}(B_d \rightarrow K^+\pi^-)$	-0.04±0.08±0.01	-0.133±0.03±0.009	-0.088±0.03±0.013

- Ratio of Bd Branching Ratios consistent with other experiments. Provides valuable cross-check for the other Branching ratio measurements
- ACP result compatible with Babar/Belle
- Systematic uncertainty at the same level
  - σ(CDF) ~ σ(Babar)/0.7 for same size samples
  - CDF currently has ~3 times more events on tape:
    - same yields as current 200fb-1 Babar
  - Expect ACP measurement at ~4.5% level from available data

(does not account for latest improved tracking and inclusion of TOF in PID)

*Speaker's calculation based on HFAG2004

Results for the Bs sector

BR*10^6 , Limits @90%CL

	CDFII preliminary 180 pb-1	Beneke&Neubert NP B675, 333(2003)
$N(B_s \rightarrow K^+ K^-)$	232/180 pb^{-1}	
$BR(B_s \rightarrow K^+ K^-)$	$0.50 \pm 0.08 \pm 0.07 * BR(B_d \rightarrow K\pi) * (fs/fd)$ = $34.3 \pm 5.5 \pm 5.2$*	[23 - 36]
$BR(B_s \rightarrow K^+ \pi^-)$	< $0.11 * [BR(B_d \rightarrow K\pi) * (fs/fd)]$ $\Rightarrow$ < 7.55*	[7 - 10]

- $BR(B_s \rightarrow K^+ K^-)$ measured with resolution 15%(stat)+15%(syst)
- Value at high end of expected range, compatible with the S4 parameter set by Beneke&Neubert [NP B675, 333(2003)], favored by fit of BR data of the Bd.
- BsKK/BdKpi = 1.85±0.4 rather than ~1 as expected by neglecting spectator effect. This value agrees with predictions based on sum rules [A.Khodyamirian et al., Phys.Rev D68(2003) 114007]
- No evidence for $B_s \rightarrow K^+ \pi^-$, 90%CL limit close to lowest expectation.
- Eventually plan to measure A_{CP} in this channel (expected ±10%)

*Based on $BR(B_d \rightarrow K^+ \pi^-)$ and fs/fd from PDG2004

Limits on rare Bd, Bs modes

BR*10^6 , Limits @90%CL

	CDF/180 pb^{-1}	PDG 2004	expectations
$BR(B_d \to K^+K^-)$	$< 0.17 * BR(B_d \to K^+\pi^-)$ $\Rightarrow$ < 3.1*	< 0.6	[0.01 - 0.2] [Beneke&Neubert]
$BR(B_s \to \pi^+\pi^-)$	$< 0.10 * BR(B_s \to K^+K^-)$** $\Rightarrow$ < 3.4*	< 1700	0.42 ± 0.06 [Li et al. hep-ph/0404028] [0.03 - 0.16] [Beneke&Neubert]

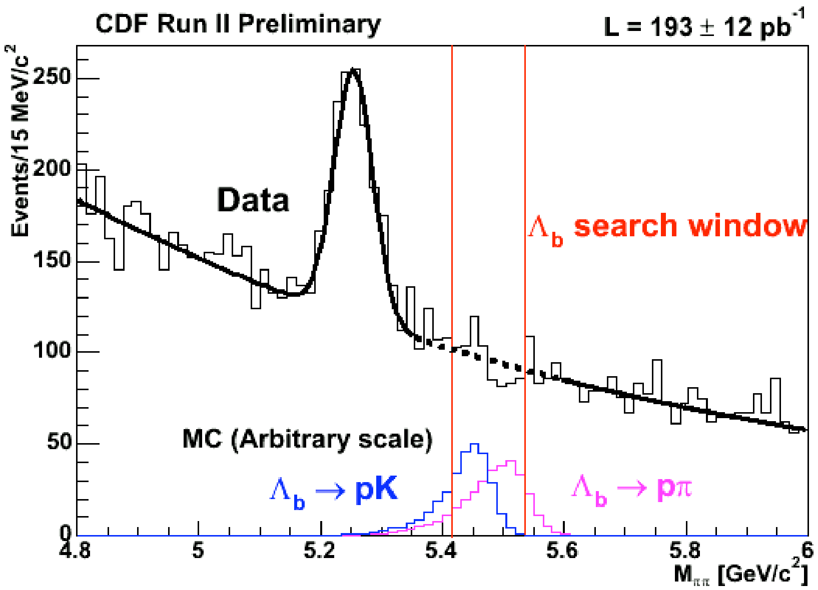
- Decays dominated by annihilation/exchange diagrams, hard to evaluate in QCDF or LCSR - experimental data important to reduce theory uncertainties.
- Current CDF limit for BR(Bd$\to$ KK) not very informative. Note: typical expected limit with current statistics is ~2x lower than observed.
- Greatly improved limit on Bs$\to\pi^+\pi^-$, now just a factor x8 above PQCD expectation. Constraints the size of annihilation diagrams also contributing to Bs$\to$KK.
- Both limits might still be improved by a targeted analysis.

*Based on $BR(B_d \to K^+\pi^-)$ from PDG2004

* *Assume equal lifetimes for KK and $\pi\pi$ modes

Beyond mesons…charmless Λ_b

- Use the same data to look for evidence of charmless Λ_b decays to ph^-
  - Large direct CP asymmetries expected
- Predictions:
  - $BR(\Lambda_b \rightarrow pK)$, $BR(\Lambda_b \rightarrow p\pi) \sim 10^{-6}$ - $2*10^{-6}$ [Mohanta, Phys. Rev. D63:074001, 2001]
- Current limits:
  - $BR(\Lambda_b \rightarrow pK) < 50*10^{-6}$ @90% C.L.
  - $BR(\Lambda_b \rightarrow p\pi) < 50*10^{-6}$ @90% C.L.
- Blind optimization to reduce background in Λ_b mass region, including from $B \rightarrow hh'$
- Normalize to $BR(B_d^0 \rightarrow K\pi)$



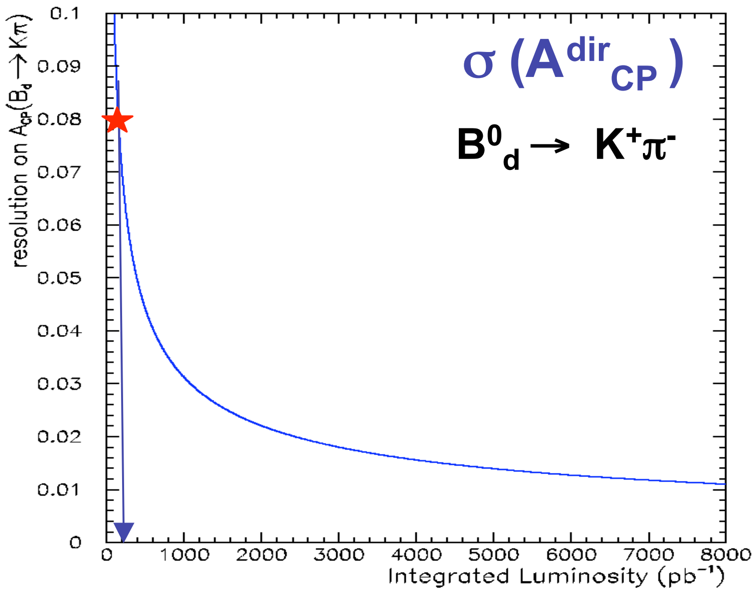
Using f_Λ/f_d=0.25±0.04:

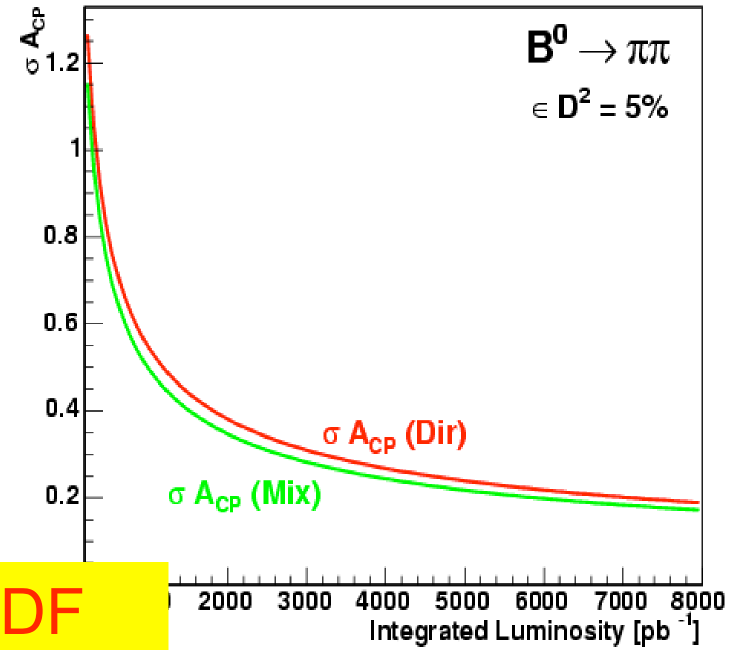
$BR(\Lambda_b \rightarrow p\pi) + BR(\Lambda_b \rightarrow pK) < 22 *10^{-6}$

Improved sensitivity in the future with proton PID from TOF+dEdx

Conclusions and prospects

- CDFII is now a player in the field of charmless 2-body B decays - increasingly important with Tevatron higher luminosity.
- Unique results on Bs modes:
  Bs → KK, Bs → Kπ , Bs → ππ,
- Much more to come:
  - Precision BR(Bs→KK)
  - Bs→KK lifetime → $\Delta\Gamma_s$
  - Bs → Kπ BR and direct A_{CP}
  - Λ_b→ ph BR and direct A_{CP}
  - Precision A_{CP}(Bd→Kπ) (eventually 1%)
- Tagged time-dependent measurements further ahead:
  A_{CP} parameters for Bd→ππ and Bs→KK





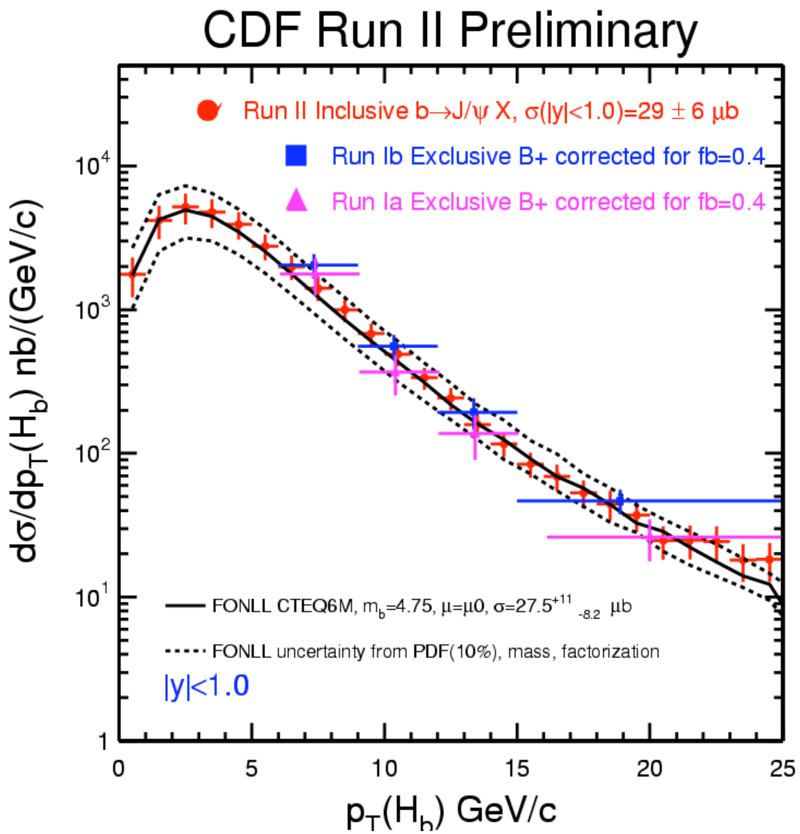
Expect valuable CKM information from CDF

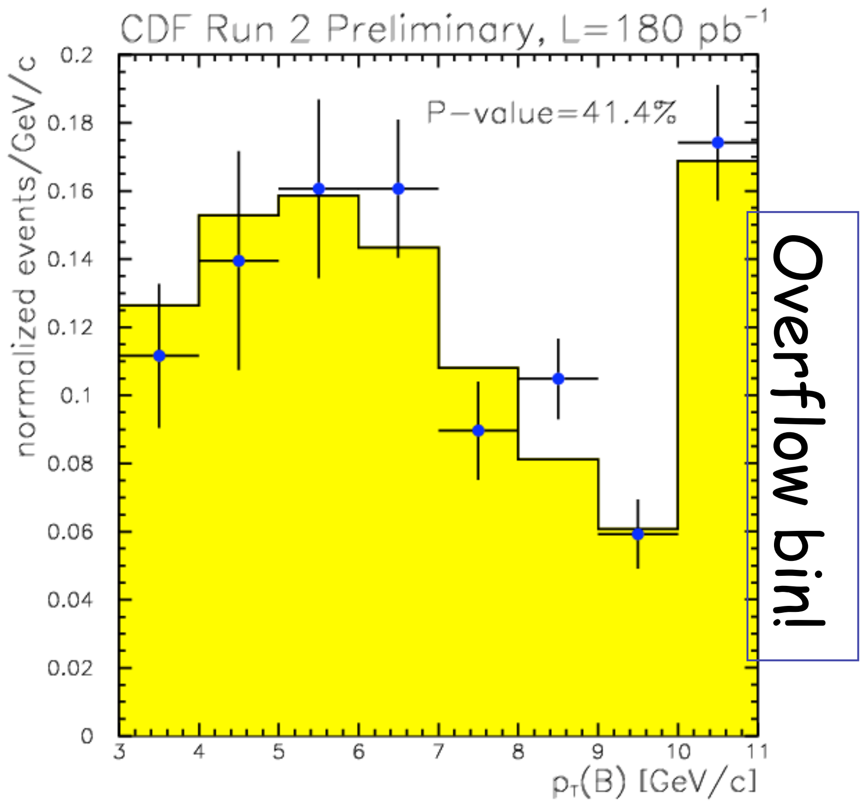
BACKUP

Summary of systematics

source	$\frac{f_s}{f_d} \cdot \frac{BR(B_s \to KK)}{BR(B_d \to K\pi)}$	$A_{\mathrm{CP}}(B_d \to K\pi)$	$\frac{BR(B_d \to \pi\pi)}{BR(B_d \to K\pi)}$	$\frac{f_d}{f_s} \cdot \frac{BR(B_d \to \pi\pi)}{BR(B_s \to KK)}$
mass resolution	$^{+0.001}_{-0.004}$	$^{+0.001}_{-0.001}$	$^{+0.001}_{-0.002}$	$^{+0.001}_{-0.001}$
dE/dx **correlation: RMS(s)**	$^{+0.043}_{-0.031}$	$^{+0.002}_{-0.002}$	$^{+0.034}_{-0.025}$	$^{+0.029}_{-0.017}$
dE/dx **correlation:** *pdf* **(s)**	$^{+0.002}_{-0.002}$	$^{+0.002}_{-0.002}$	$^{+0.000}_{-0.000}$	$^{+0.002}_{-0.002}$
dE/dx **tail**	$^{+0.056}_{-0.056}$	$^{+0.003}_{-0.003}$	$^{+0.020}_{-0.020}$	$^{+0.017}_{-0.017}$
dE/dx **shift**	$^{+0.001}_{-0.002}$	$^{+0.001}_{-0.001}$	$^{+0.001}_{-0.003}$	$^{+0.017}_{-0.005}$
input masses	$^{+0.027}_{-0.028}$	$^{+0.003}_{-0.003}$	$^{+0.009}_{-0.010}$	$^{+0.009}_{-0.010}$
background model	$^{+0.005}_{-0.005}$	$^{+0.002}_{-0.002}$	$^{+0.003}_{-0.003}$	$^{+0.000}_{-0.000}$
lifetime	$^{+0.004}_{-0.004}$	-	-	$^{+0.004}_{-0.004}$
isolation efficiency	$^{+0.051}_{-0.051}$	-	-	$^{+0.050}_{-0.050}$
MC statistics	$^{+0.004}_{-0.004}$	$^{+0.001}_{-0.001}(*)$	$^{+0.003}_{-0.003}$	$^{+0.006}_{-0.006}$
charge asymmetry	-	$^{+0.002}_{-0.002}$	-	-
XFT-bias correction	$^{+0.010}_{-0.007}$	-	$^{+0.004}_{-0.004}$	$^{+0.015}_{-0.010}$
$\boldsymbol{p_T(B)}$ **spectrum**	$^{+0.007}_{-0.007}$	-	-	$^{+0.007}_{-0.007}$
$\boldsymbol{\Delta\Gamma_s/\Gamma_s}$ **Standard Model**	$^{+0.007}_{-0.006}$	-	-	$^{+0.006}_{-0.006}$
TOTAL	$\pm$**0.09**	$\pm$**0.01**	$\pm$**0.04**	$\pm$**0.07**

Production Pt spectra





B→ hh trigger accept very soft B → big samples available!

Measurement of the production Pt spectrum from inclusive b→JψX in this region important for reliable MC simulation

Sensitivity to a possible large value of $\Delta\Gamma_s$

$$\frac{f_s \cdot BR(B_s \to K^\pm K^\mp)}{f_d \cdot BR(B_d \to K^\pm \pi^\mp)} = 0.50 \pm 0.08 \pm 0.09$$

CDF measurement from $B_s \to J/\psi\, \phi$

Contains some assumptions on lifetimes:

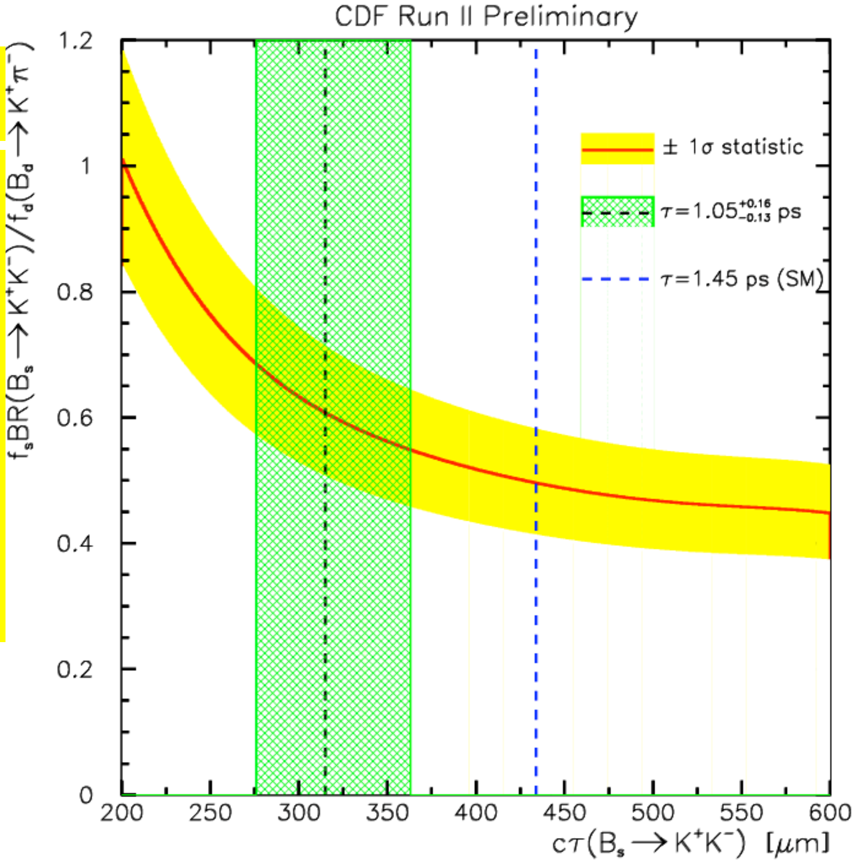
$dN(B_s \to KK)/dt \propto R_L \exp(-t_L) + R_H \exp(-t_H)$

- $R_H = 0$ (no Heavy Bs decay to KK or, equivalently, no tree contribution)

- $\tau_L = 1/(\Gamma_s + \Delta\Gamma_s/2) = 1.45$ ps

(SM: $\Delta\Gamma_s/\Gamma_s = 0.12 \pm 0.06$ and $\Gamma s = \Gamma d$)

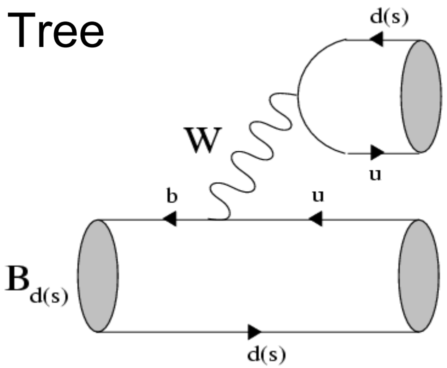
Figure: acceptance-corrected BR vs assumed average $B_s \to KK$ lifetime



Large $\Delta\Gamma_s \Rightarrow$ even larger BR(BsKK)

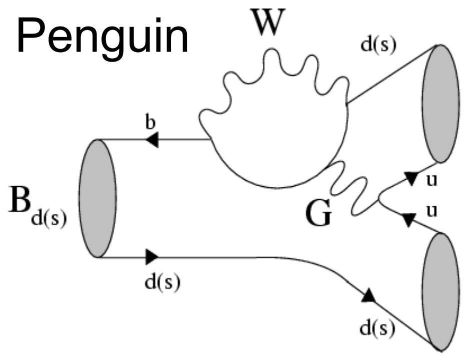
$B_{d(s)} \rightarrow hh'$ penguin and tree

Tree



Amplitude ~ T

Penguin



Amplitude ~ P

$$A(B_d \rightarrow \pi^+\pi^-) = C\left[e^{i\gamma} - de^{i\vartheta}\right]$$

$$A(B_s \rightarrow K^+K^-) = \left(\frac{\lambda}{1-\lambda^2/2}\right)C'\left[e^{i\gamma} + \left(\frac{1-\lambda^2}{\lambda^2}\right)d'e^{i\vartheta'}\right]$$

Glossary

C, C' : CP conserving strong amplitudes

d, d' : "penguin to tree ratio"

θ, θ' : strong phase difference between penguin and tree

Amplitudes related by U-spin symmetry of strong interactions (s↔d interchange) !

$$d = d' \; ; \; \vartheta = \vartheta'$$